Mechanical and Tribological Behavior of Aluminum Honeycomb Core Reinforced with Polypropylene Composite

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A B S T R A C T

Development of new Polymeric Matrix Composite are continuously increasing to meet out the industrial needs. In this paper new composite was developed by Aluminum Honeycomb Core structure was reinforced Polypropylene and it was characterized for mechanical and tribological properties. The characterization of mechanical properties like tensile strength, flexural strength, Impact strength and hardness of Aluminium honeycomb core reinforced with Polypropylene has been investigated over pure Polypropylene shows remarkable improvement in mechanical properties. Also in the Tribological characterization was done by using two-body abrasive wear test for the Aluminum Honeycomb Core structure reinforced Polypropylene composite. Abrasive wear experiments were conducted using a pin-on-disc wear tester under dry contact condition. Normal load, sliding velocity, sliding distance and abrasive paper grit size are considered as the design processes parameters and Coefficient Of Friction & Specific Wear Rate are considered as the responses. The design of experiments are based on L9 Orthogonal array used for this study. The optimum combination of process parameters for minimum Coefficient Of Friction are 30 N normal load, 1.046 m/sec sliding velocity, 450 m sliding distance and 320 grit size of abrasive paper and 30 N load, 1.569 m/sec sliding velocity, 450 m sliding distance and 400 grit size of abrasive gives minimum specific wear rate was obtained by using Analysis of Variance. Coefficient of friction is significantly influenced by the normal load, grit size. Specific wear rate is significantly influenced by sliding distance, normal load. Optical microscopy of worn surfaces revealed that wear mechanism is adhesive and abrasive, and there was a good bonding between Aluminium honeycomb core and Polypropylene.

Keywords: Aluminum honeycomb core, Polypropylene, Taguchi analysis, Two-body abrasion

1. Introduction

Polymer composites are formed by combining two or more materials which are having different properties. Composite materials are commonly used in automotive, chemical industries, aerospace, construction etc. [1]. Composite materials find applications for a variety of parts because they offer the combinations of properties which cannot be attained with metals, ceramics or polymers alone. Polymer composites have, therefore, replaced many traditional metallic materials for sliding components. The increasing use of polymer composites in sliding components has made the studies of the tribological behavior of these materials a commercial necessity. To reach the tailor-made properties of material for the specific tribological applications, it is only possible by choosing right composition and right fabrication process for polymeric matrix composites [2]. Selecting optimum filler-matrix ratio, size and shape of the filler, compatible filler-matrix interfacial bonding will give good properties of composite materials [3]. The properties may be improved further by reinforcements and fillers [4] resulting in higher strength, high wear resistance, low coefficient of friction, etc. The properties of such a composite would be affected by the distribution of polymer phases, the compatibilizer used for adhesion between the Phases, and the type of reinforcement or filler [5]. Polypropylene compounds are widely used in structural components that require higher levels of stiffness, strength and heat resistance and are predominantly used in a number of Automotive, Appliance and Furniture applications. Aluminum honeycomb core is a lightweight, environmental friendly material with good...
mechanical properties, lightweight, stiffness, fire resistance, compression, corrosion resistance. Aluminum honeycomb sheets can be used in tool machines, as core for lightweight panels.

2. Experimental
2.1. Materials: Polypropylene (PP) and Aluminium honeycomb core (AHC)
PP was used as matrix material and AHC was used as a reinforcing material. AHC made of alloy 3003 H18 of thickness 4.9 mm and cell size of 6 mm were used. Compression Moulding was carried out to produce plates of dimension 150 x 150 x 9 mm$^3$. Initially the empty die was placed between the top and bottom heaters and it was pre heated up to 200°C. When the required temperature was reached the AHC and PP sheet materials were kept inside the die and heated for 10 mins. The compression moulding pressure was set to 150 bars. Then pressure was applied in such a way that AHC can be reinforced between PP sheets. After heating for the preset time it was air cooled for 24 hours. Fig. 1 shows fabrication process of composite material. Three samples were prepared by taking different percentage of AHC with PP. Table 1 shows composition of AHC and PP matrix in different samples.

![Fig. 1 Stages of fabrication of AHC with PP](image1)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Composites</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S-0</td>
<td>100wt. %PP + 0wt. % AHC</td>
</tr>
<tr>
<td>2</td>
<td>S-1</td>
<td>98wt. %PP + 2wt. % AHC</td>
</tr>
<tr>
<td>3</td>
<td>S-2</td>
<td>96wt. %PP + 4wt. % AHC</td>
</tr>
</tbody>
</table>

2.2. Preparations of specimens
The mechanical tests conducted based on American Standard Testing Methods (ASTM). There were four tests performed, namely Tensile Test, Flexural Test, Impact Test and Shore D hardness test. Test specimens and ASTM standards are shown in the Table 2.

3. Results and Discussion
3.1. Mechanical characterization of AHC/PP composite
The characterization of AHC reinforced PP was carried out as per the ASTM standards. The test results shows the improvement of material properties. The Test results are shown in Table 3.

3.1.1. Tensile test of AHC/PP composite
After reinforcement of AHC, the composite material become strong in tension. This is because of strong bonding between AHC and PP. During tensile testing of fabricated composite material a large part of loading was taken by AHC. Since metal are having more strength as compared to plastic material, the load required to break the specimen is increased because of presence of AHC. Again by increasing the Aluminium percentage in the AHC/PP composite material, the load taking capacity of AHC/PP compositematmaterial increases. Fig 3 shows a comparison of ultimate tensile strength between the pure PP and AHC/PP composite with different percentage of aluminium.

![Fig. 2 AHC/PP composite](image2)

<table>
<thead>
<tr>
<th>Test method</th>
<th>Standards</th>
<th>Macrograph of the sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Test</td>
<td>ASTM D 638-14</td>
<td><img src="image3" alt="Image" /></td>
</tr>
<tr>
<td>Flexural Test</td>
<td>ASTM D 790-10</td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td>Impact Test</td>
<td>ASTM D 256-10</td>
<td><img src="image5" alt="Image" /></td>
</tr>
<tr>
<td>Hardness Test</td>
<td>ASTM D 2240-05</td>
<td><img src="image6" alt="Image" /></td>
</tr>
</tbody>
</table>

3.1.2. Flexural test of AHC/PP composite
It was observed that the reinforcement of AHC increases bending strength. Since metals have high strength as compared to plastic, so, load required to break the specimen increases. Again by increasing the Aluminium percentage in the composite material, the load taking capacity of AHC/PP composite material increases. Fig. 4 and Fig. 5 shows a comparison of Flexural strength and Flexural modulus respectively between the Pure PP and AHC/PP composite.
3.1.3. Impact test of AHC/PP composite
It was observed that the material with 2wt. % of AHC shows higher Impact strength as compared to 4wt. % of AHC. So it is obvious that strength increases when the wt. % of Aluminium increases in PP. Addition of aluminium causes to increase the ductile property of the material. Because of increase in ductility of the composite material the toughness of the material also increases.

3.1.4. Hardness test of AHC/PP composite
The strength of a metal is more than plastic, so by reinforcing AHC in PP the resistance against penetration increases for the composite material. Again by increasing the Aluminium percentage in the composite material, cause more resistance against penetration. So the addition of aluminium increases the Hardness of the material.

3.2. Friction and wear test
Taguchi method is an efficient and powerful tool for the optimization of process parameters. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). In the present study, S/N ratio is calculated as the logarithmic transformation of the loss function by using smaller-the-better criterion as minimum values of friction coefficient and specific wear rate are required.

\[ S/N \text{ ratio} = -10 \log\left(\frac{1}{n} \sum y^2\right) \]  

(1)

Where, y is experimental data for COF and specific wear rate and n denotes the number of experiments.

Table 3 Mechanical characterization of AHC reinforced with PP

<table>
<thead>
<tr>
<th>Properties</th>
<th>100wt. %PP(S-0)</th>
<th>98wt. %PP + 2wt. % AHC(S-1)</th>
<th>96wt. %PP + 4wt. % AHC(S-2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cc)</td>
<td>0.90</td>
<td>0.94</td>
<td>0.97</td>
</tr>
<tr>
<td>Ultimate Tensile Strength(MPa)</td>
<td>6.34</td>
<td>11.69</td>
<td>12.07</td>
</tr>
<tr>
<td>Flexural Strength (MPa)</td>
<td>45.27</td>
<td>60.00</td>
<td>63.51</td>
</tr>
<tr>
<td>Flexural Modulus (GPa)</td>
<td>1.27</td>
<td>2.50</td>
<td>2.62</td>
</tr>
<tr>
<td>Izod Impacts (J/cm)</td>
<td>0.49</td>
<td>1.11</td>
<td>1.67</td>
</tr>
<tr>
<td>Shore D Hardness</td>
<td>65</td>
<td>73</td>
<td>78</td>
</tr>
</tbody>
</table>

Fig. 3 AHC reinforced with PP as stated proportion Vs ultimate tensile strength

Fig. 4 AHC reinforced with PP as stated proportion Vs Flexural strength

Fig. 5 AHC reinforced with PP as stated proportion Vs Flexural modulus

Fig. 6 AHC reinforced with PP as stated proportion Vs Impact strength
An important step in design of experiments is the selection of control factors. The factors and different levels for L9 orthogonal design is given in the Table 4.

Table 4 Factors and different levels for L9 orthogonal design

<table>
<thead>
<tr>
<th>Design factors</th>
<th>Unit</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal load (A)</td>
<td>N</td>
<td>10 20 30</td>
</tr>
<tr>
<td>Sliding velocity (B)</td>
<td>m/sec</td>
<td>0.523 1.046 1.569</td>
</tr>
<tr>
<td>Sliding distance (C)</td>
<td>M</td>
<td>150 300 450</td>
</tr>
<tr>
<td>Abrasive grit size (D)</td>
<td>µm</td>
<td>180 320 400</td>
</tr>
</tbody>
</table>

Friction and wear test for AHC reinforced PP material was conducted by using DUCOM Pin-On-Disc Tribotester according to G99-05 standard in dry sliding conditions at room temperature. The samples were cut in the dimensions of 9×9×4 mm. The material specimens were glued to the metal pin. A loading lever is used to apply load on the top of the specimen. Force sensor can measure the frictional force. The samples were weighted before and after the experiments with an accuracy of 0.0001 g in electronic balance. The formula used for calculation of specific wear rate was,

\[ K_0 = \frac{(w_1 - w_2)}{(p \times S_d \times L)} \]  \hspace{1cm} (2)

Where, \( w_1 \) and \( w_2 \) are the weight of the sample before and after the abrasion test in gm, \( p \) is the density of the composite material, \( K_0 \) is the specific wear rate in \( mm^3/N-m \), \( S_d \) is the sliding distance in meters, and \( L \) is the load in N.

3.2.1. Taguchi analysis for friction and wear test results

Two body abrasive wear test was conducted using L9 orthogonal array details of which are shown in table 5. The main effect plots for mean S/N ratios of COF and SWR are presented in Fig. 8 (a-b). In the main effects plots of COF and SWR, if the point is near the average horizontal line, it has less significant effect and the one which has highest inclination will have most significant effect on the responses. Coefficient of friction decreases with increasing

3.2.2. Analysis of variance (ANOVA) of friction and wear test results

Degrees of freedom of error become zero. So, F-ratio calculation is not possible. In this situation Pooling can be done as follows. First the lower value of sequential sum of squares is identified and corresponding parameter assumed as an error as well a degrees of freedom, and F-ratio is calculated manually. F-ratio is the ratio of adjusted mean square value to the adjusted mean square value of error. Coefficient of friction is significantly influenced by load, grit size, and sliding velocity as shown in the Fig. 9. Specific wear rate is significantly influenced by sliding distance, normal load as shown in the Fig. 10. Conformation test also conducted which shows that predicted and experimental values were varying with small
error values as shown in Table 6. Optimum combination of 30 N load, 1.046 m/sec sliding velocity, 450 m sliding distance and 320 grit size of abrasive paper gives minimum COF as shown in Fig. 8 (a), and 30 N load, 1.569 m/sec sliding velocity, 450 m sliding distance and 400 grit size of abrasive paper gives minimum SWR as shown in Fig. 8 (b). These optimum parameters were obtained by Taguchi analysis. Typical optical macrograph AHC/PP composite was shown in Fig. 11. It explains the bonding of AHC/PP composite.

**Fig. 8 Main effects plots for S/N ratio (a) COF (b) Specific wear rate**

**Fig. 9 Percentage contribution of parameters on coefficient of friction**

**Fig. 10 Percentage contribution of parameters on specific wear rate**

**Table 6 Conformation test results**

<table>
<thead>
<tr>
<th>Parameter Levels</th>
<th>Optimal parameters</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of Friction ($\mu$)</td>
<td>A3B2C3D2</td>
<td>A3B2C3D2</td>
</tr>
<tr>
<td>Specific Wear Rate (mm$^3$/Nm)</td>
<td>A3B3C3D3</td>
<td>A3B3C3D3</td>
</tr>
</tbody>
</table>

3.3. Worn Surface Morphology of friction and wear test surface

To understand the material removal mechanism, the worn surfaces of composite specimens were examined using Optical Microscopy images. Abrasive wear occurs by three different mechanisms i.e. micro-cutting, micro-ploughing and micro-cracking. Fig. 12 shows the optical microscopy images for 10 N normal load. Wear debris, micro-crack and wear groove depths are clearly observed. On the other hand in Fig. 13 at higher load, micro cracks, wear debris and wear groove depths are increased. It is also observed that near the AHC reinforcement wear was not occurred [9].

**Fig. 12 Optical Microscopy of worn Surfaces under 10 N load**

**Fig. 13 Optical Microscopy of worn Surfaces under 30 N load**

4. Conclusion

The experimental research work carried out on fabrication of AHC reinforced PP composite, the following conclusions can be drawn:

- It has been observed from the characterization of mechanical properties like tensile strength, flexural strength, impact strength and hardness
of AHC reinforced PP increased as compare to pure PP.

- Coefficient of friction decreases as the normal load or grit size of the abrasive paper increases. Specific wear rate also linearly decreases with increase of abrading distances as well as grit size of the abrasive paper.
- The optimum combination of parameters for minimum coefficient of friction were 30 N load, 1.046 m/sec sliding velocity, 450 m sliding distance and 320 grit size of abrasive paper and for minimum specific wear rate were 30 N load, 1.569 m/sec sliding velocity, 450 m sliding distance and 400 grit size of abrasive paper.
- Coefficient of friction is significantly influenced by load, grit size, and sliding velocity and Specific wear rate is significantly influenced by sliding distance and normal load.
- The worn surface morphology for composites shows the sliding direction, wear debris, plasticization of matrix and cracking.

References


